TIMING IN PACKET NETWORKS

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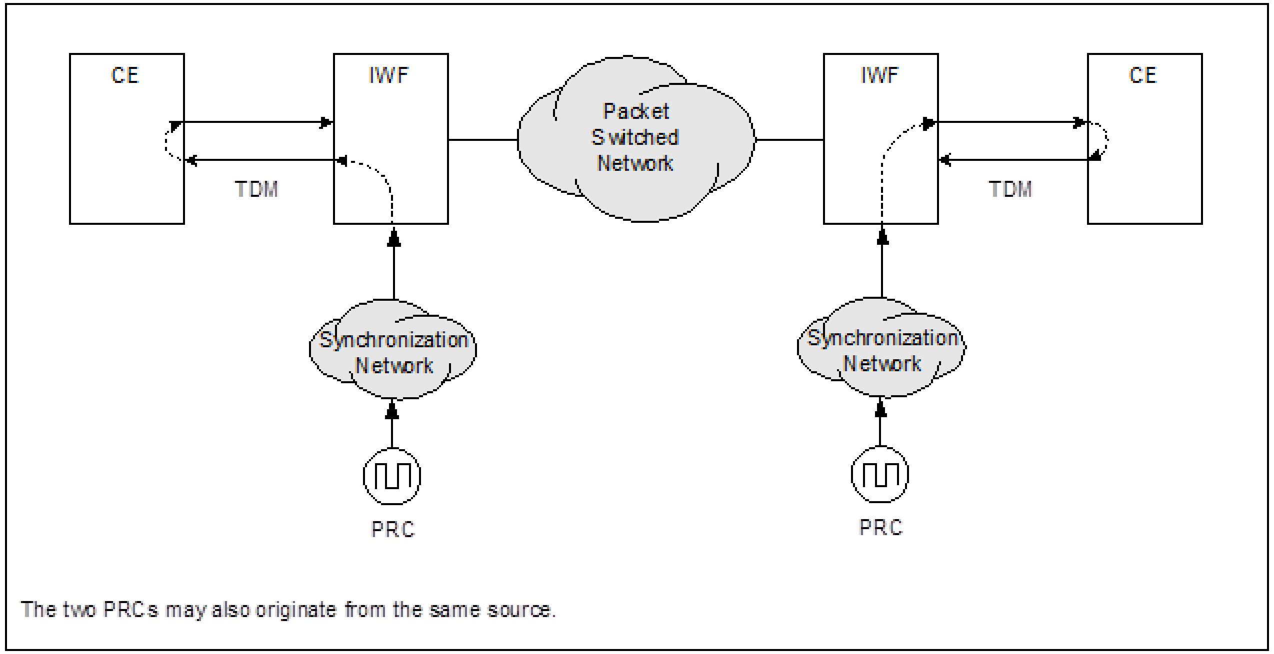
- Background
- Frequency sync via packets
- Two-Way Time Transfer
- NTP/PTP Details
- Impairments, Packet-based Metrics for frequency and time

  - Note: Special thanks to Christian Farrow (Chronos) and Kishan Shenoi (Qulsar)

HISTORICAL BACKGROUND

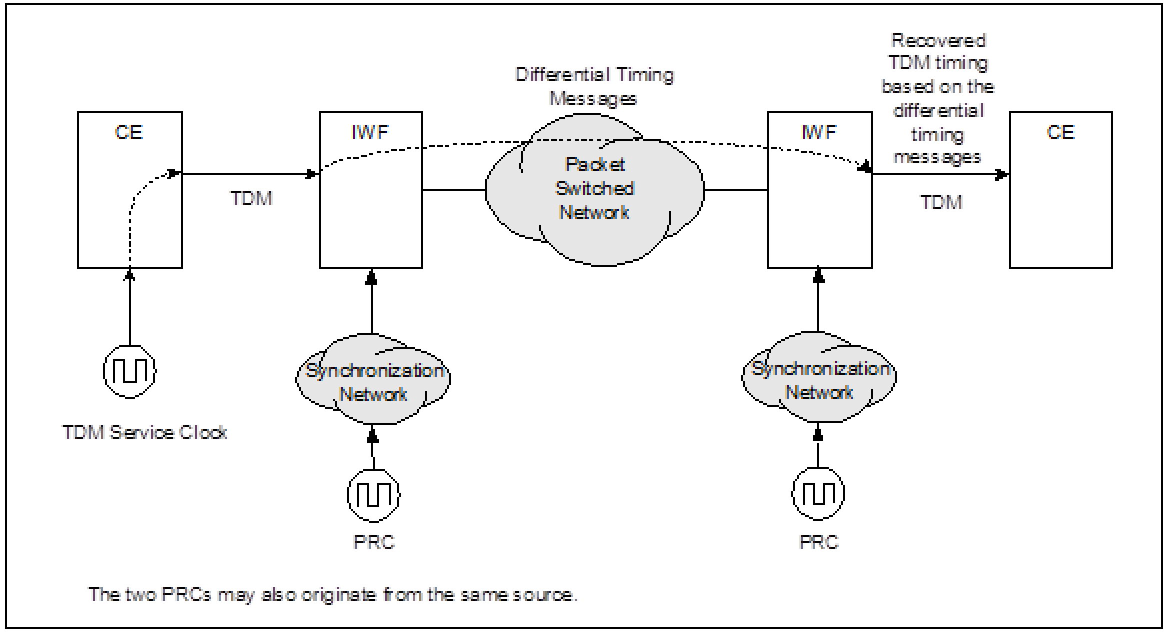
- Packet Switching network does not require sync itself
- CBR (Constant Bit Rate) services carried over ATM one of the first examples when sync aspects discussed in relationship with packet technologies
  - Definition of methodologies to recover the CBR sync rate have been defined to allow the transport of these services over ATM (eg. 2 Mbit/s):
    - Network Synchronous
    - Adaptive
    - Differential
- The migration of the transport network to packet networks (in particular IP), led to a generalization of these methods,
  - Need to support timing requirements of the connected networks (e.g. Mobile applications)
  - Circuit Emulation detailed performance analysis
  - Frequency sync distribution via dedicated protocols (NTP, PTP)
  - Standardized performance objectives over reference networks (ITU-T Recc. G.8261)
- Recent increase interest to also deliver time/phase sync reference
  - Packet-based technologies required

CIRCUIT EMULATION SYNC SOLUTIONS: PRC AVAILABLE AT THE EDGES OF THE PACKET NETWORK



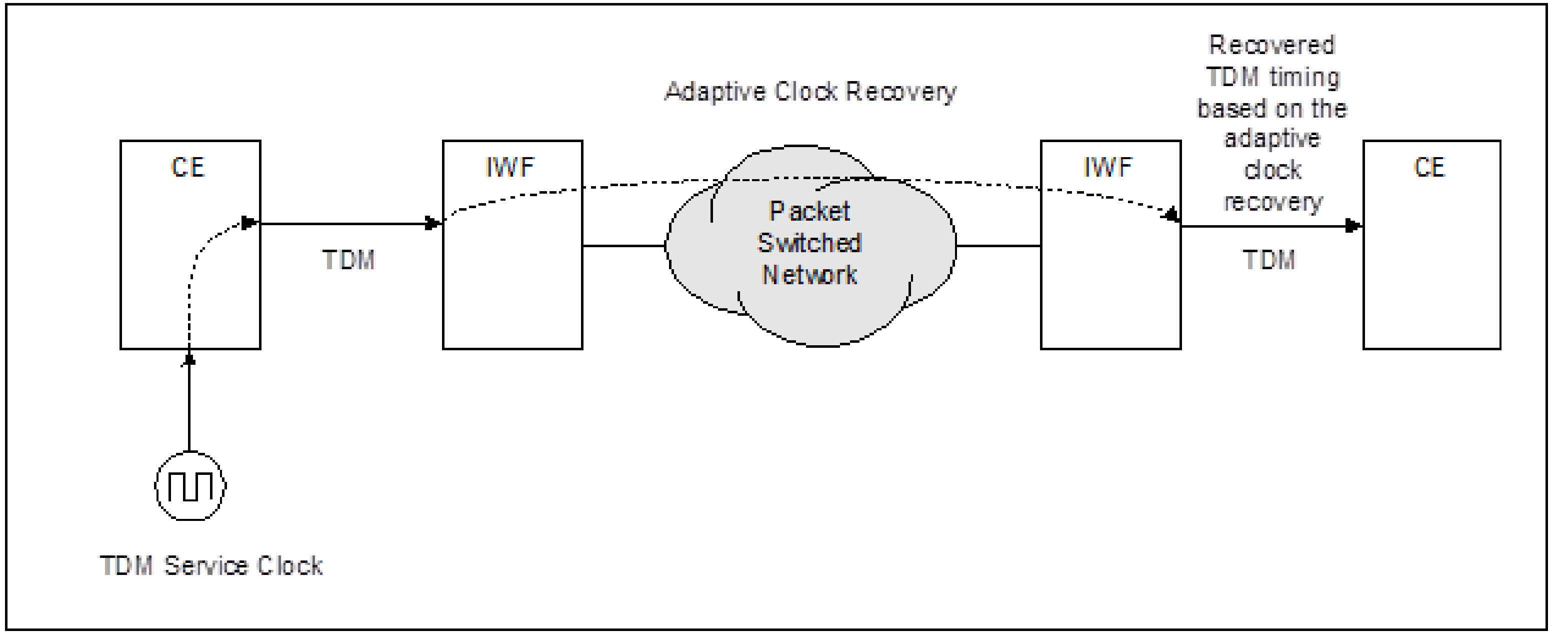
Network Synchronous

Differential



From ITU-T Recc. G.8261

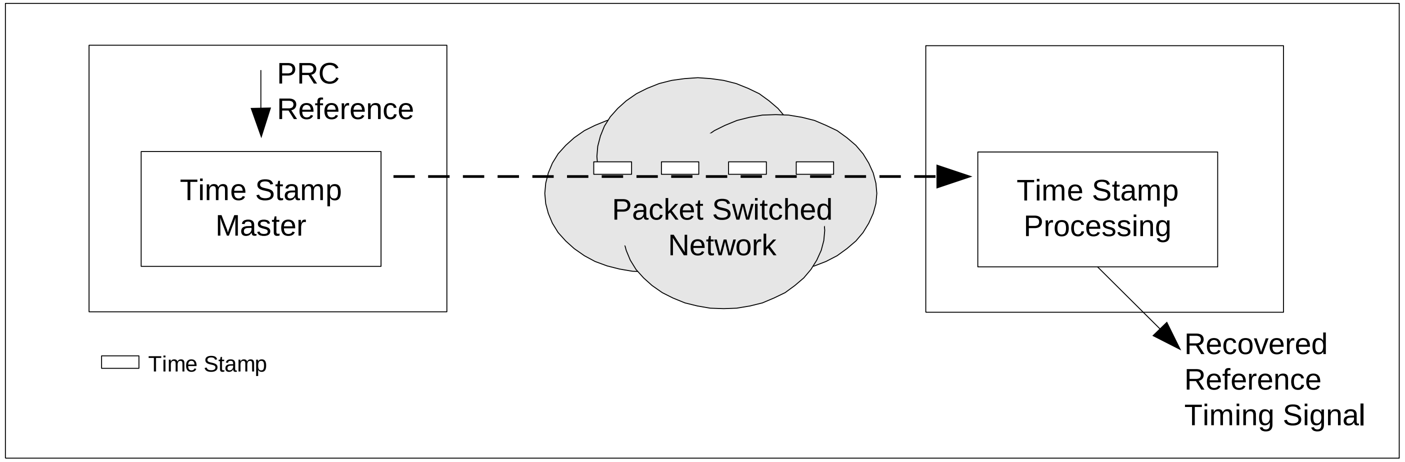
CIRCUIT EMULATION: ADAPTIVE METHODS



From ITU-T Recc. G.8261

- No PRC traceable reference available at the edge of the packet network !
  - Frequency sync recovered based on arrival time of the packets ...

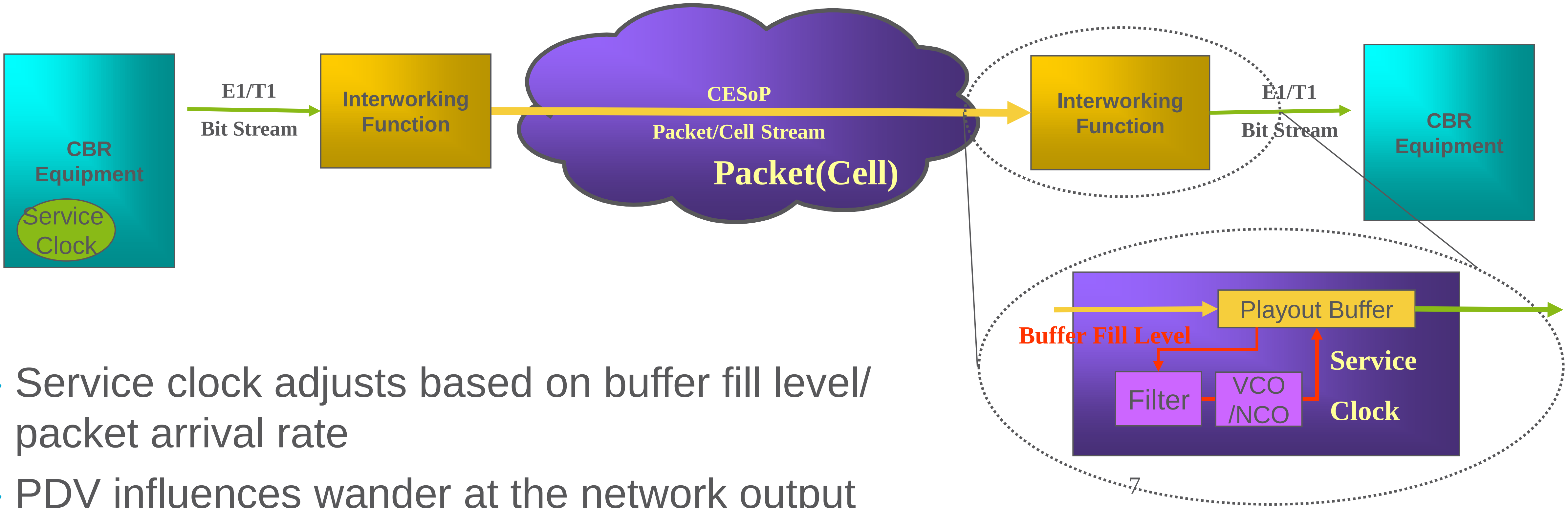
PACKET-BASED METHODS



From ITU-T Recc. G.8261

- Timing information carried by *dedicated* timing packets:
  - Network Time Protocol (NTP)
  - Precision Time Protocol (PTP)

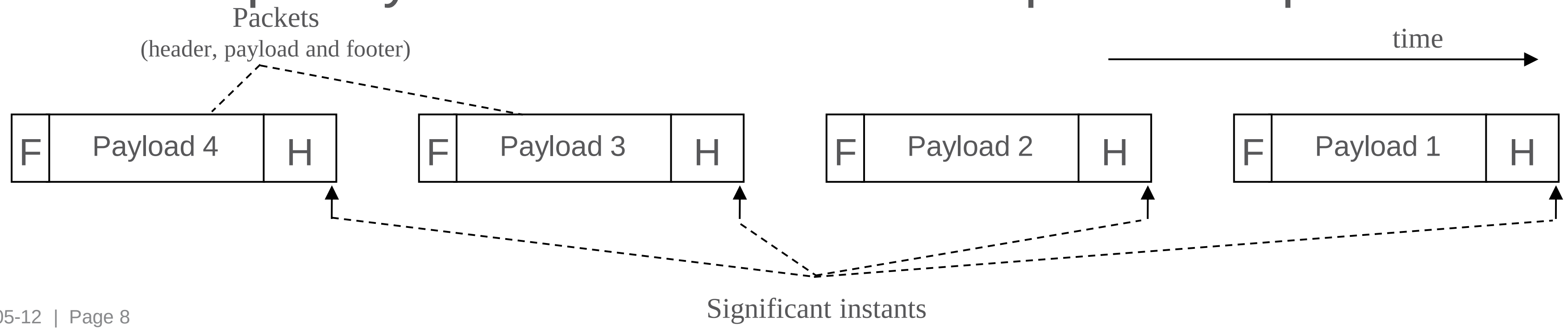
ADAPTIVE CLOCK OPERATION



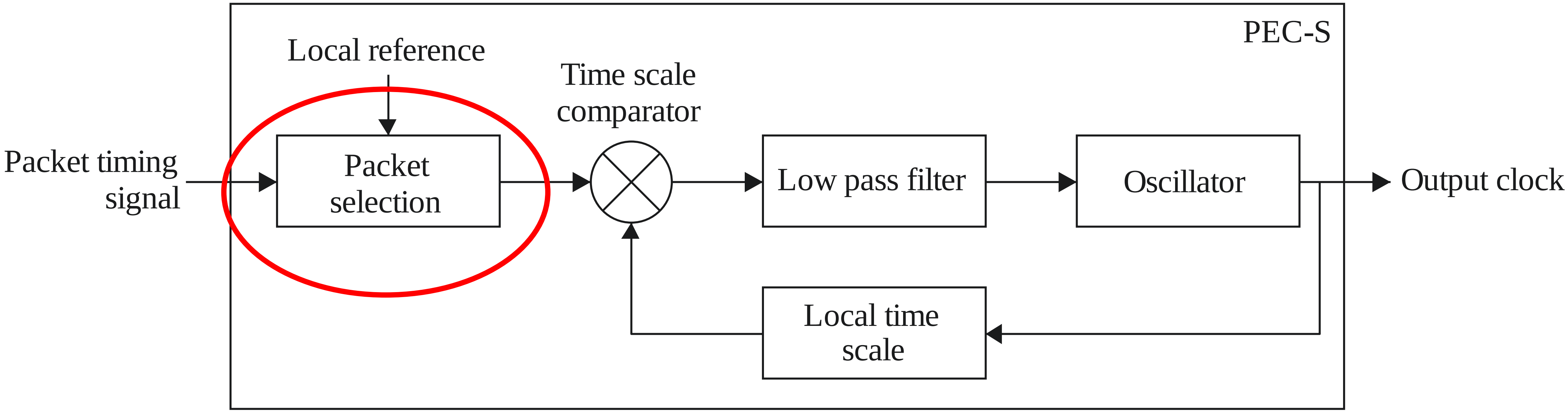
- Service clock adjusts based on buffer fill level/ packet arrival rate
- PDV influences wander at the network output

FROM CLOCKS TO “PACKET CLOCKS”

- “Packet clocks” can be described in a similar way …
- CES Packets do have a regular rhythm
- Extension to using dedicated protocols: NTP, PTP
  - NTP/PTP Packets may not arrive regularly, but timestamps within the packets themselves mean time information can be extracted
  - Timing information contained in the arrival/departure time of the packets
  - Timestamps carried by the packets can be used to support this operation
  - Two-way or one-way protocols
  - Timing recovery process based on filtering the PDV
- Time and frequency can be distributed from point A to point B



PACKET-BASED EQUIPMENT CLOCK

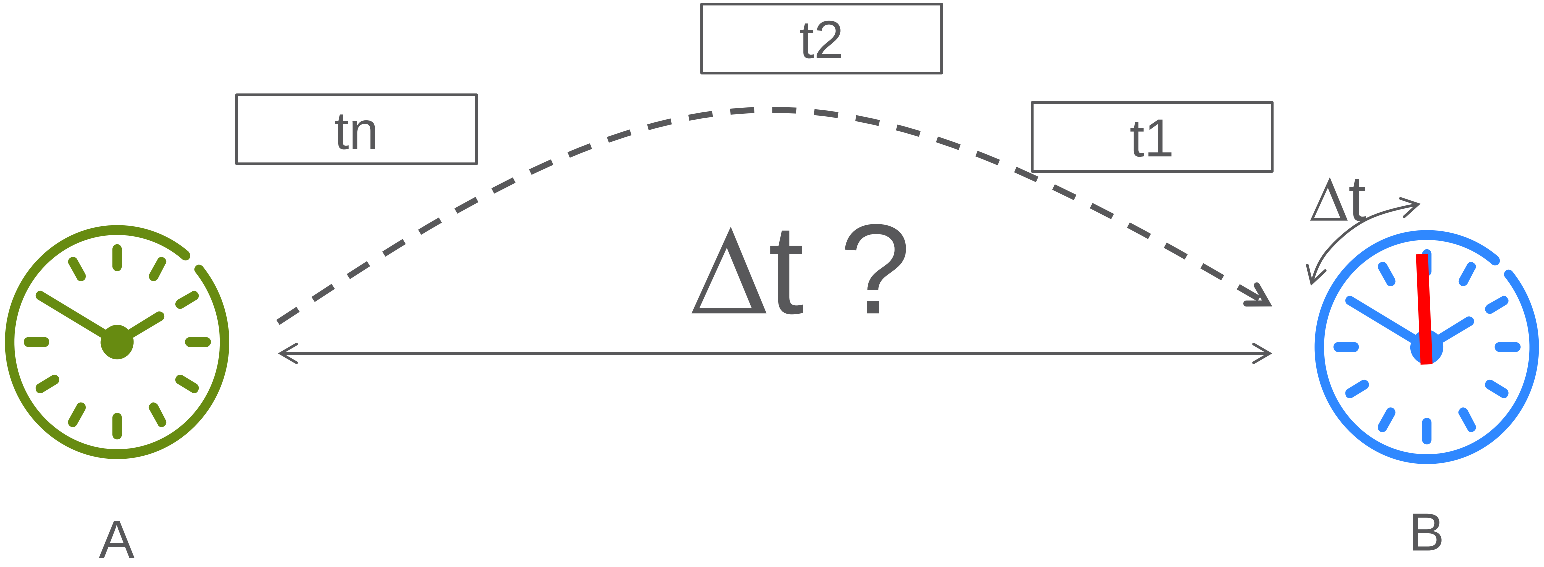


G.8263-Y.1363(12)_FA.1

› Concept of «Packet Selection»:
  - Pre-processing of packets before use in a traditional clock to handle PDV

TWO-WAYS TIME TRANSFER

- Delivery of Time synchronization requires also the knowledge of «transit delay» from A to B

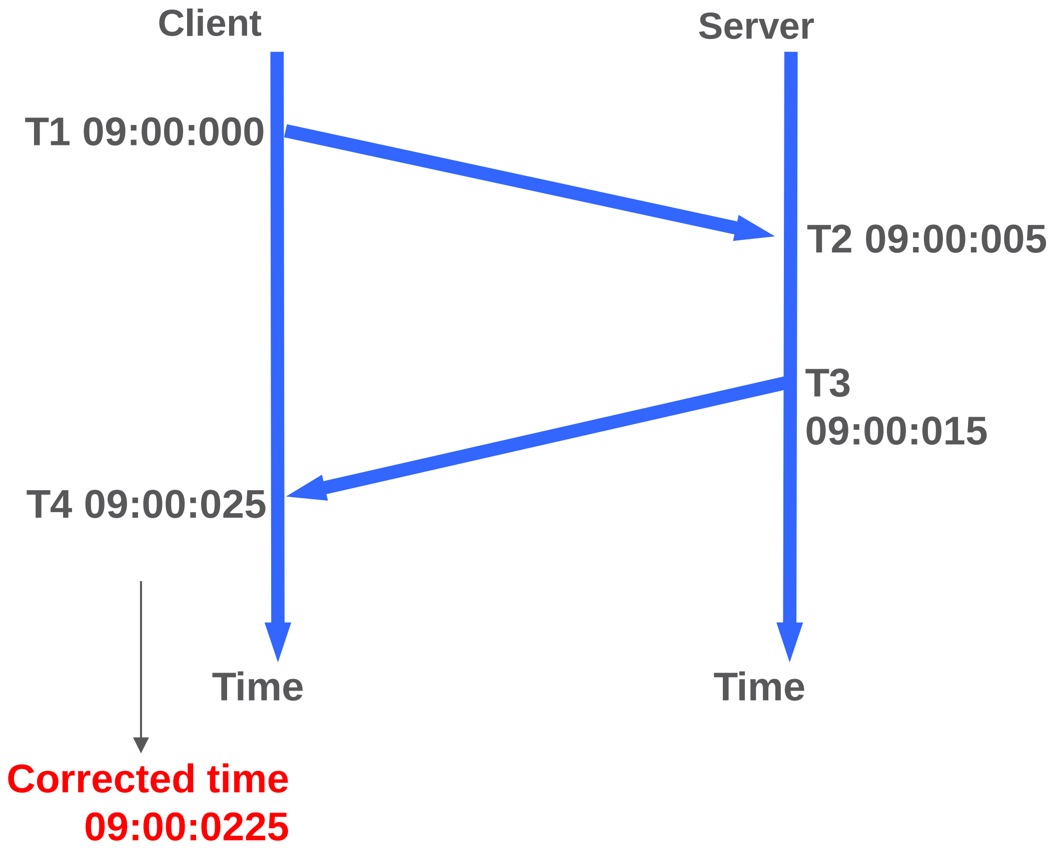


- Two-ways transfer protocols (round trip delay)
  - Assumption for symmetric channel

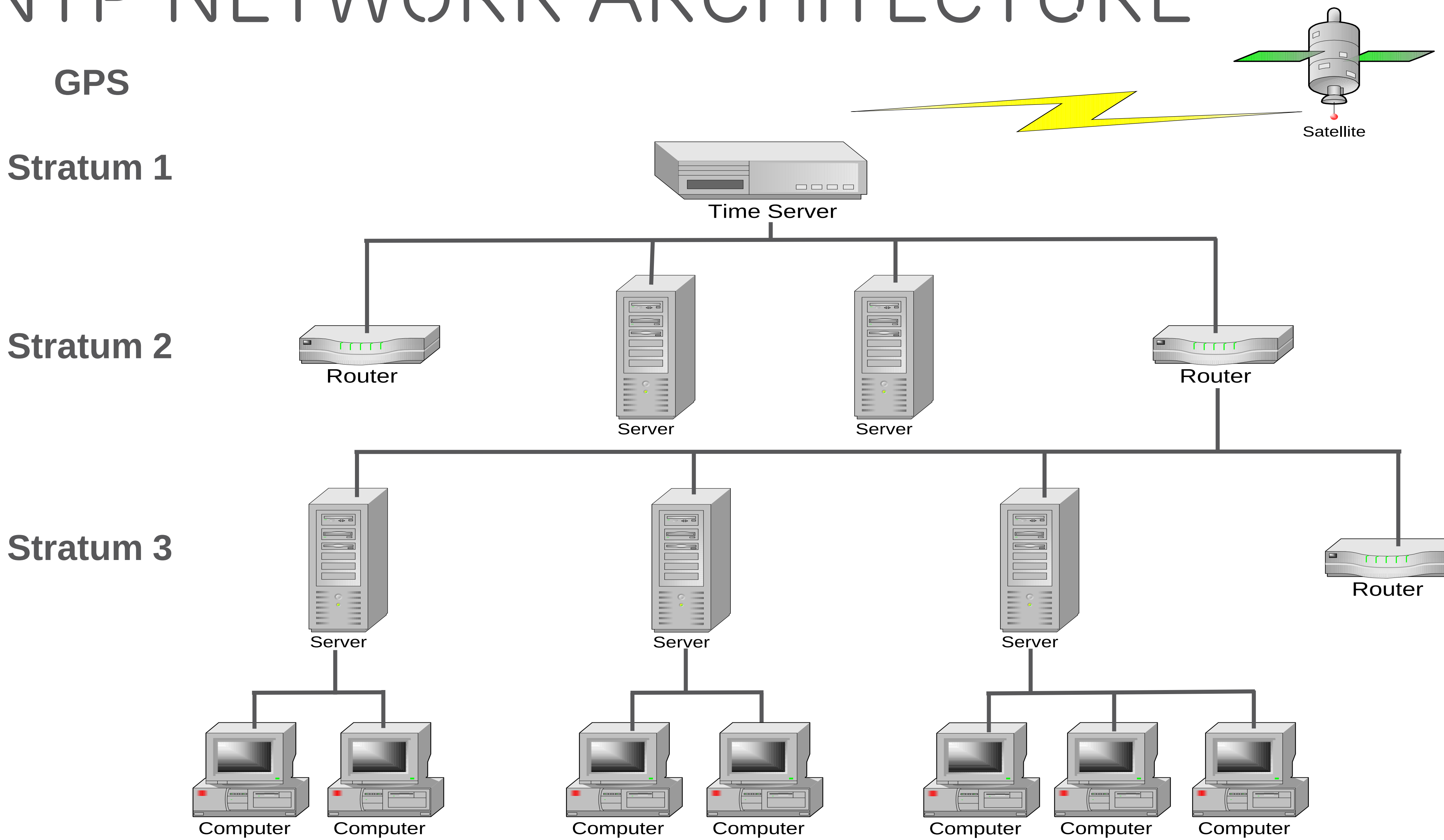
HOW NTP WORKS

- T1 Originate Timestamp
  - Time request sent by client
- T2 Receive Timestamp
  - Time request received by server
- T3 Transmit Timestamp
  - Time reply sent by server
- T4 Destination Timestamp
  - Time reply received by client
- Round Trip Delay=(T4-T1)-(T3-T2)
  - Round Trip Delay =25-10=15
- Clock Offset= [(T2-T1)-(T4-T3)]/2
  - Clock Offset =[5-10]/2= **-2.5** (Clients actual time when reply received was therefore **09:00:0225**)

- **Key Assumptions:**
  - **One way delay is half Round Trip (symmetry!)**
  - Drift of client and server clocks are small and close to same value
  - Time is traceable



NTP NETWORK ARCHITECTURE



IEEE 1588-2008 PTPV2 OVERVIEW

› The Grandmaster “reference clock” sends a series of time-stamped messages to slaves.

› Slaves process the round-trip delay & synchronize to the Grandmaster.

› Frequency can be recovered from an accurate time of day reference (but L1 can also be used …)

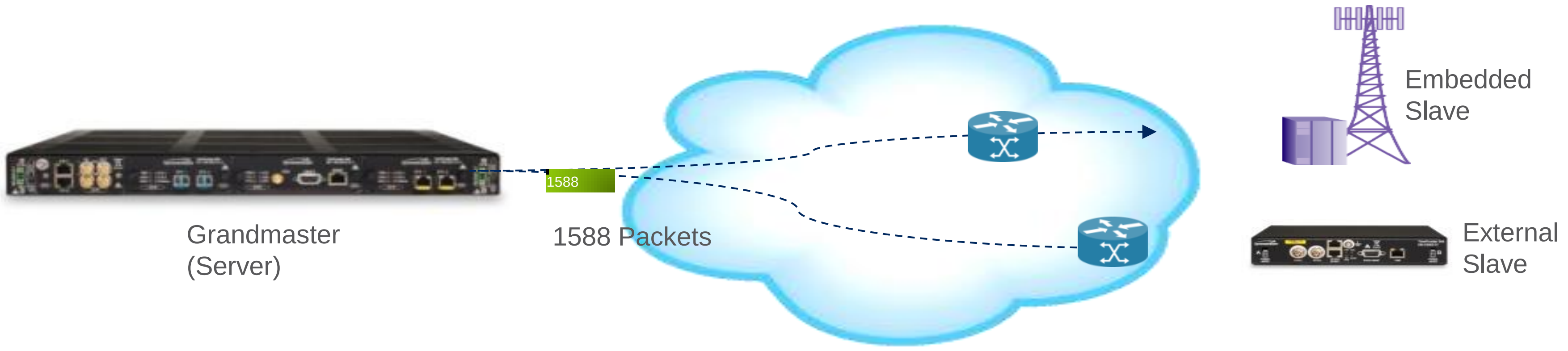
› Best Master Clock Algorithm to define the hierarchy

› Accuracy is possible by means of:

  – Proper packet rate (up to 128 per second)

  – Hardware time-stamping (eliminate software processing delays)

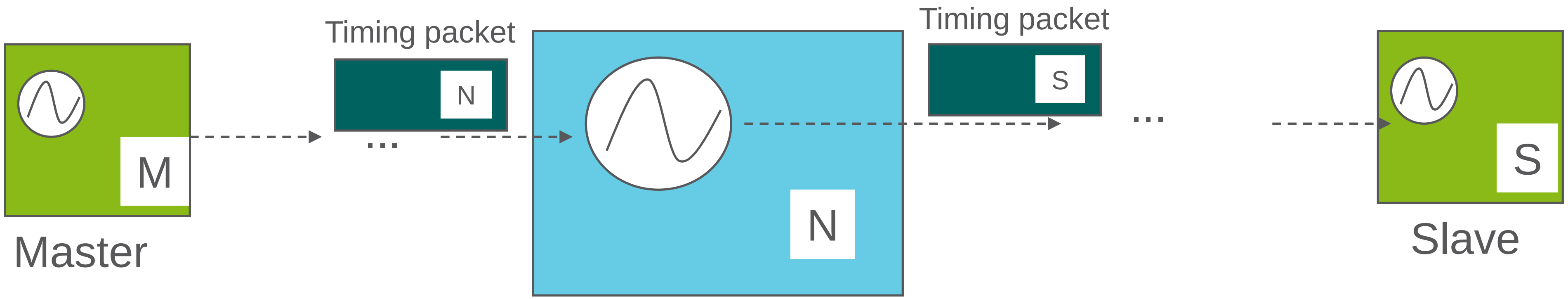
  – Timing support in the network



Packet Slave clocks can be either stand-alone or embedded in network equipment

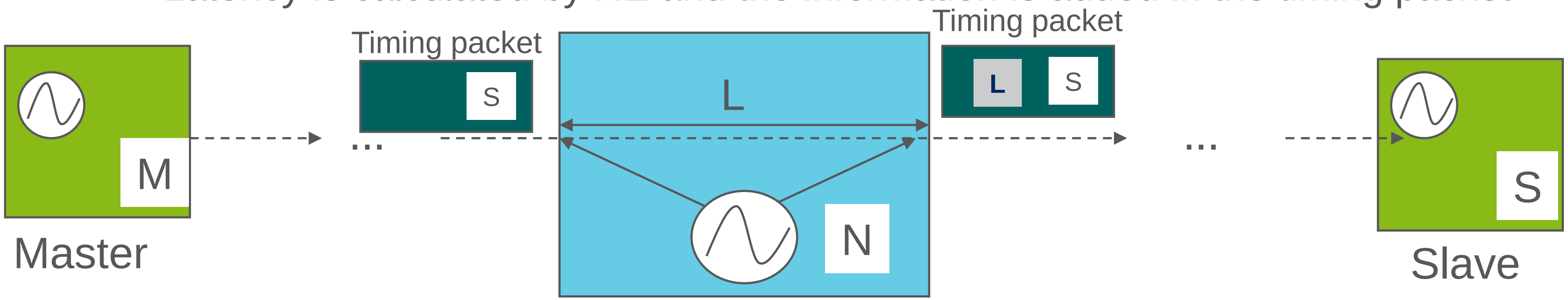
TIMING SUPPORT

Timing packets are terminated and regenerated by N



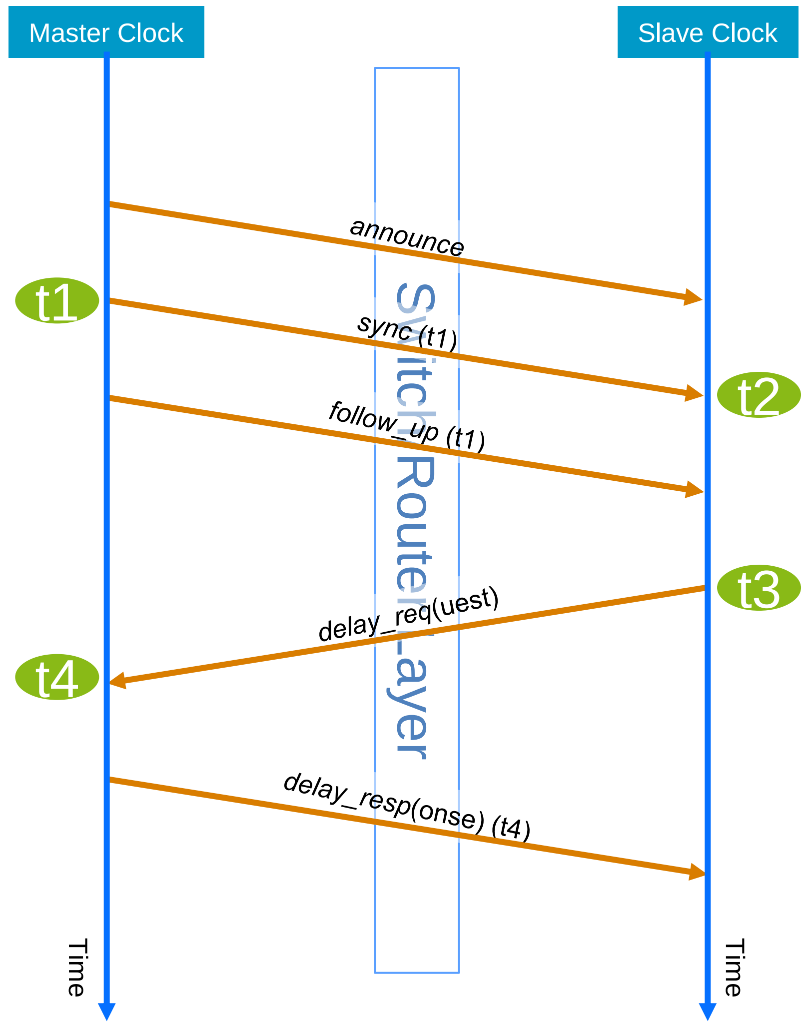
e.g. IEEE1588 Boundary Clock, NTP Stratum Clock

Latency is calculated by NE and the information is added in the timing packet



e.g. IEEE1588 Transparent Clock

PTP TIME TRANSFER TECHNIQUE



The process is repeated up to 128 times per second.
(Announce rate is lower than Sync rate)

Data At Slave Clock

Leap second offset

t2 (& t1 for 1-step)

t1,t2

t1, t2, t3

t1, t2, t3, t4

Round Trip Delay

RTD = (t2 - t1) + (t4 - t3)

Offset:

(slave clock error and one-way path delay)

$Offset_{SYNC}$ = t2 – t1

$Offset_{DELAY\_REQ}$ = t4 – t3

We assume path symmetry, therefore

One-Way Path Delay = RTD ÷ 2

Slave Clock Error = (t2 - t1) - (RTD ÷ 2)

Notes:

1. One-way delay cannot be calculated exactly, but there is a bounded error.
2. The protocol transfers TAI (Atomic Time).
   UTC time is TAI + leap second offset from the *announce* message.

"THE TELECOM PROFILE" (G.8265.N/G.8275.N)

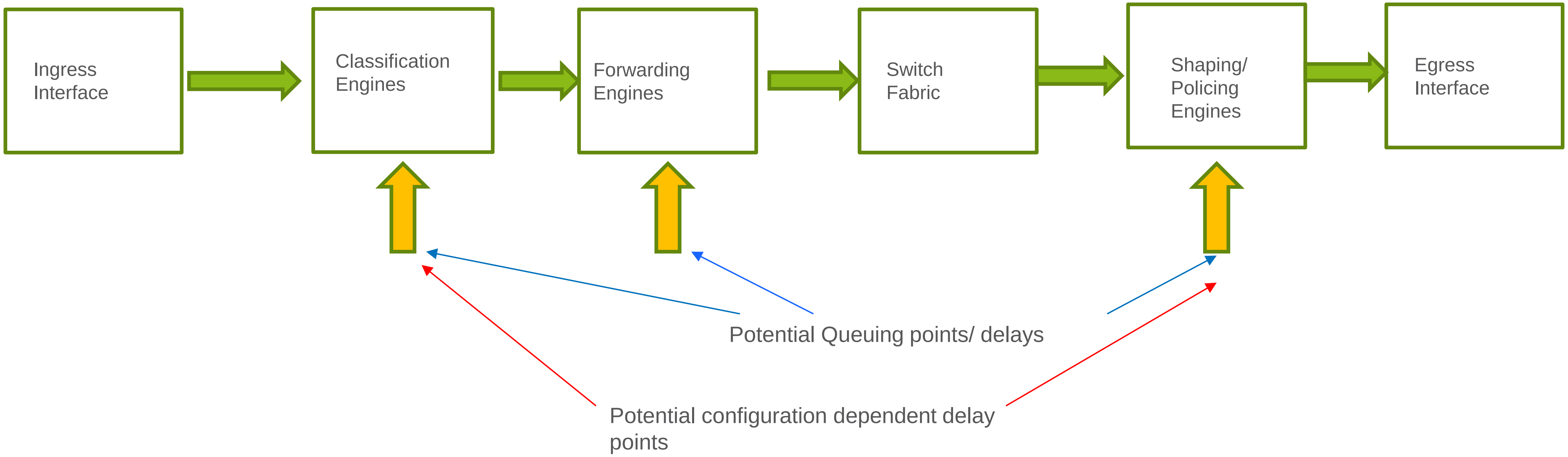
- A profile is a subset of required options, prohibited options, and the ranges and defaults of configurable attributes
  - e.g. for Telecom: Update rate, unicast/multicast, etc.
- PTP profiles are created to allow organizations to specify selections of attribute values and optional features of PTP that, when using the same transport protocol, inter-works and achieve a performance that meets the requirements of a particular application
- *Other (non-Telecom) profiles:*
  - IEEE C37 238 Power Distribution Industry
  - 802.11AS AV bridging (AV over domestic LAN)

IMPAIRMENTS IN PACKET NETWORKS

- Typical Impairments in the packet networks
  - Packet delay variations [PDV], depending on
    - Network dimension
    - Traffic load
    - QoS
  - Path dependent aspects
    - Physical path asymmetry (*particularly relevant for time synchronization*)
    - Path rerouting
  - Interactions between the packet streams

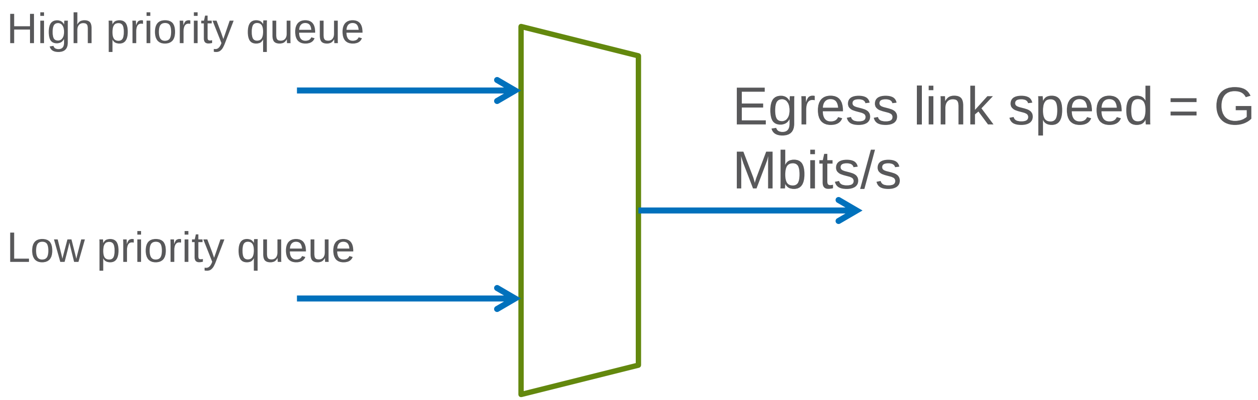
PACKET DELAY VARIATION (PDV)

- Queuing
- Equipment Configuration
- Priority/ QoS



PACKET DELAY VARIATION (PDV), CONT.

› Head of line blocking



MTU size M byte
Strict priority queue

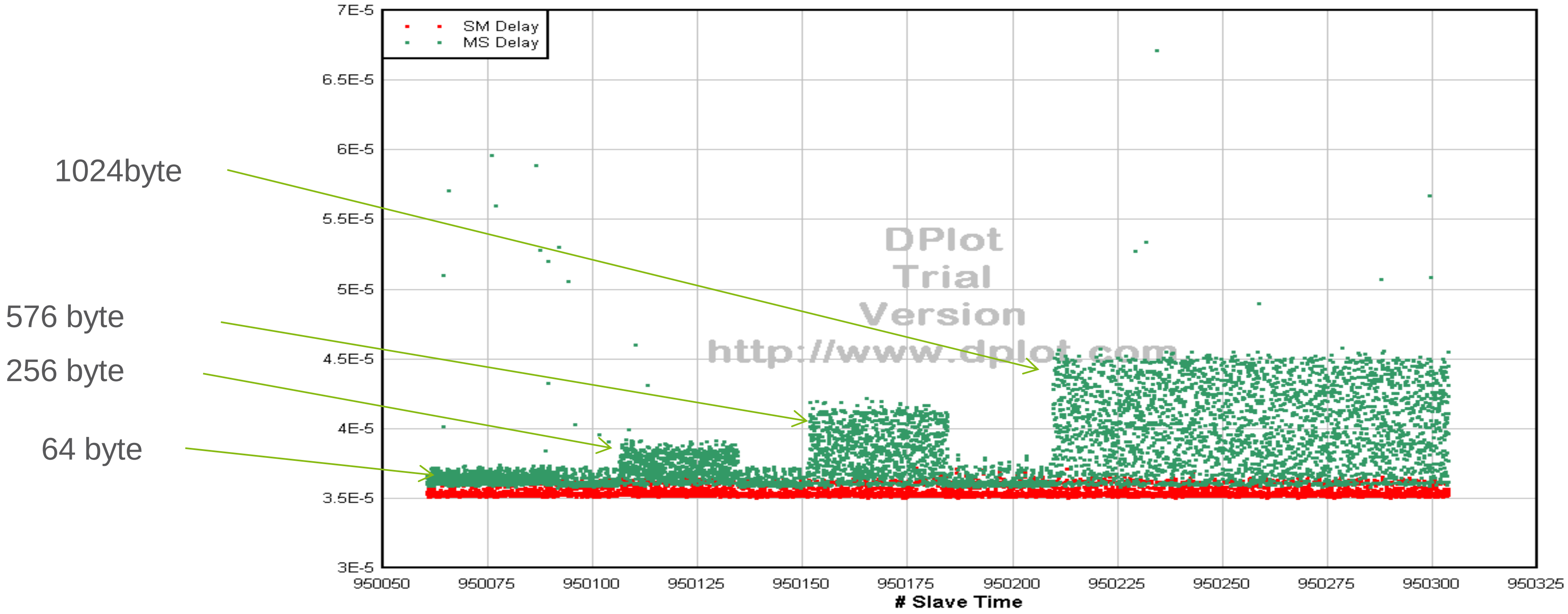
$$(\Delta_{pp})_{max} \geq \left(\frac{M}{G} \right) \mu s$$

- A packet arrives in the HPQ, just when a packet from the LPQ has begun transmission
- The packet from HPQ is blocked till the LPQ packet is transmitted
- With more complex prioritization scheme the delay due to head of line blocking could vary significantly

Ex. : at 100 Mbit/s, 1000 byte packet = 8 x 1000 / 100 x 106 = 80µs

PACKET DELAY VARIATION (PDV), CONT.

Equipment implementation specifics
e.g. the Delay variation through a single piece of equipment, with packet sizes



PATH DEPENDENT IMPAIRMENTS

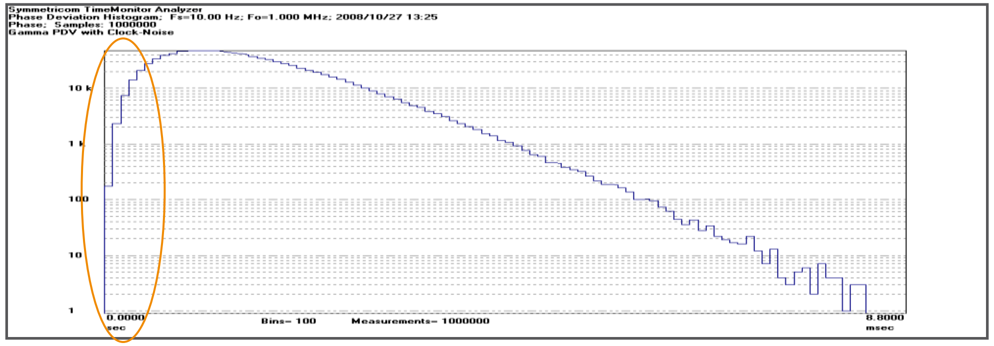
- Asymmetry
  - Static Difference in paths between the forward and reverse paths. E.g difference in lengths of fiber
  - Forward and reverse paths pass through different node
- Rerouting
  - Leads change in path delays and can “confuse” the algorithms.

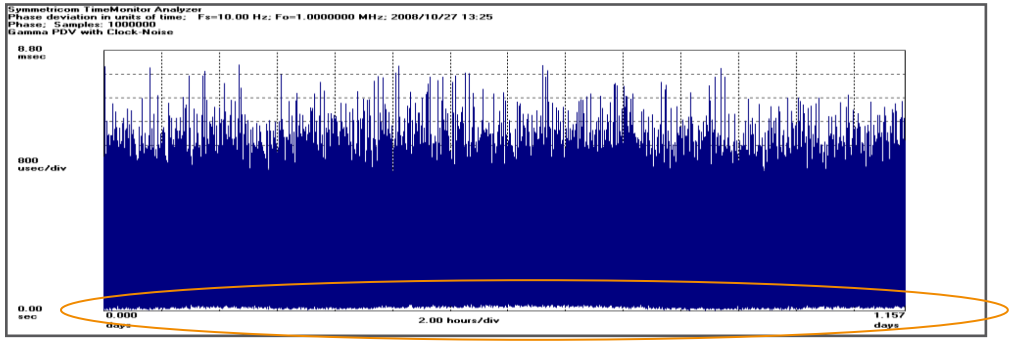
KEY ASPECTS OF PERFORMANCE

- Packet Delay Variation (PDV) is a major contributor to “clock noise”
  - Related to number of hops, congestion, line-bit-rate, queuing priority, etc. Time-stamp-error can be viewed as part of PDV
- Clock recovery involves low-pass-filter action on PDV
  - Oscillator characteristics determine degree of filtering capability (i.e. tolerance to PDV)
    - Higher performance oscillators allow for longer time-constants (narrower bandwidth == stronger filtering)
    - Lower performance (less expensive) oscillators may be used (may require algorithmic performance improvements)
- Performance improvements can be achieved by
  - Higher packet rate
  - Controlling PDV in network (e.g. network engineering, QoS)
  - Timing support from network (e.g. *boundary clocks* in PTP)
  - Packet selection and/or nonlinear processing

NOTION OF "BEST PACKETS"

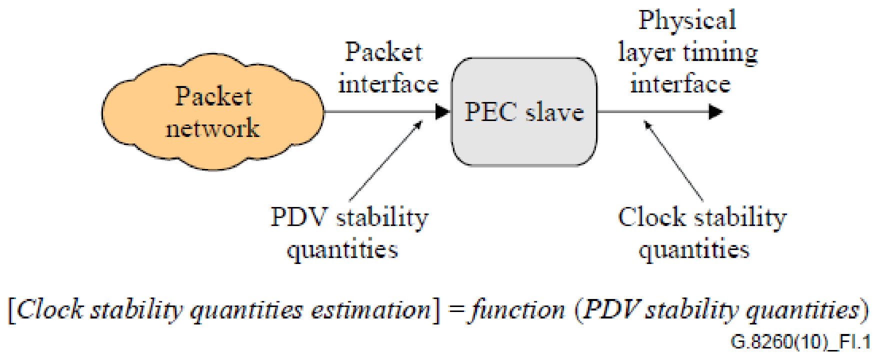
- The impact of PDV can be mitigated by means of a suitable classification and selection of packets
- The "minimum delay" approach is presented as an example. Depending on the network characteristics other approaches may be more suitable
- The assumption that the path is constant over the interval of observation implies a PDV with a distribution function with a slowly changing floor (i.e. minimum delay that a packet can experience)
- In many cases it has been observed that a reasonable fraction (e.g. x%) of the total number of packets will traverse the network at or near this floor
- Using only these packets in the timing recovery mechanism would allow to significantly reduce the impact of the PDV on the quality of the recovered reference timing signal



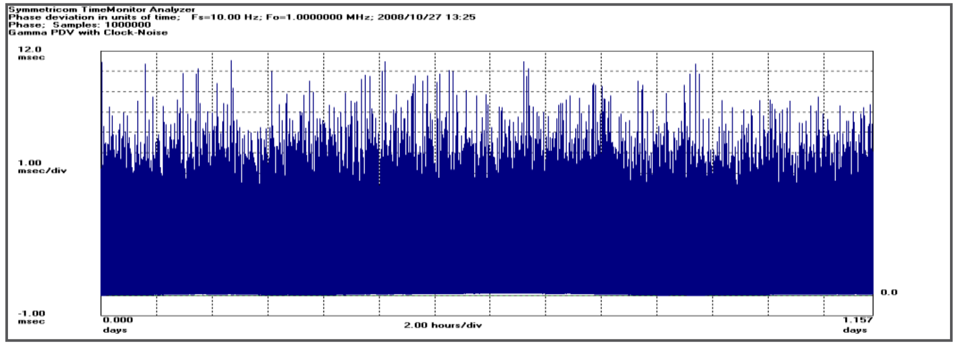


SYNC METRICS IN PACKET NETWORKS

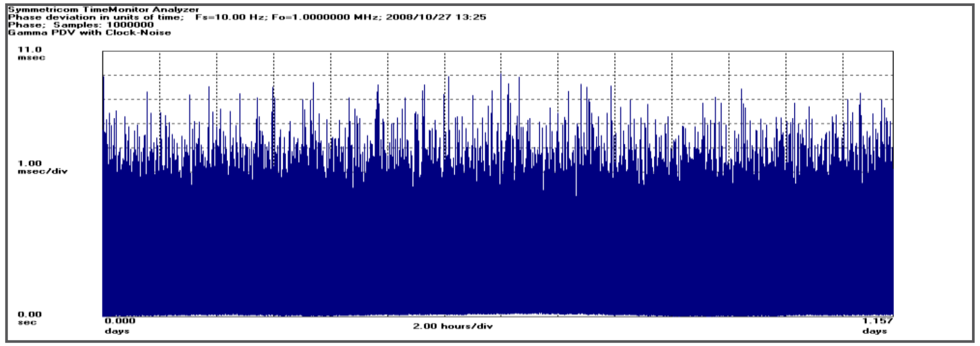
- The Network Element clock output metrics (computed from TIE measurements) can be the same (MTIE/MRTIE/TDEV)
  - Clock output requirements are determined by existing (or modified) masks
  - Some distinctions are required in case of packet clock integrated in the Base Station (no standardized output MTIE/TDEV by 3GPP)
- Specific Metrics have been defined to better characterize the behavior of packet networks (PDV) delivering the timing reference
  - E.g. metrics that associate PDV with Frequency Offset or phase variation
  - Tolerance masks/Network limits are used by network operators and clock manufacturers
  - Packet selection methods can be justified

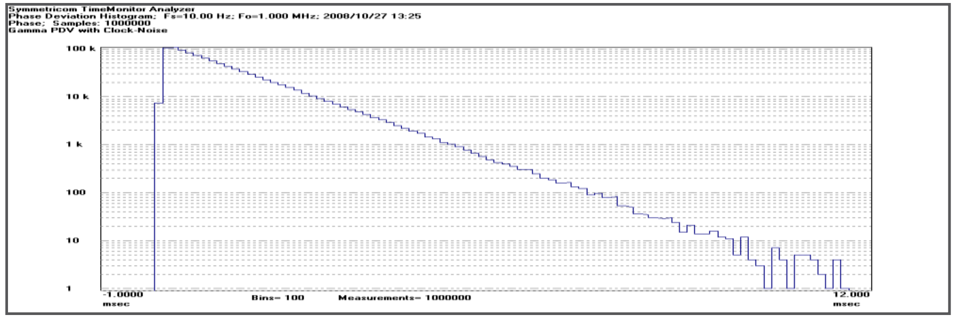


PEAK-TO-PEAK JITTER NOT SUFFICIENT



phase





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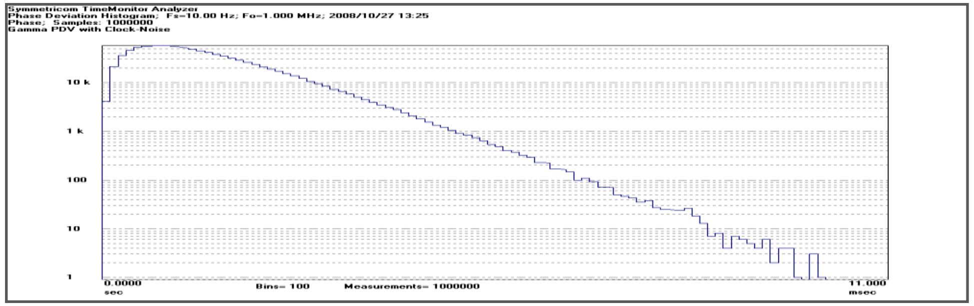
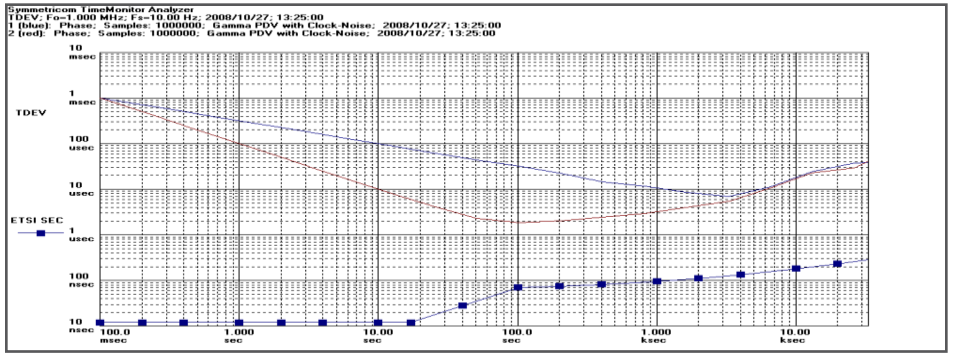
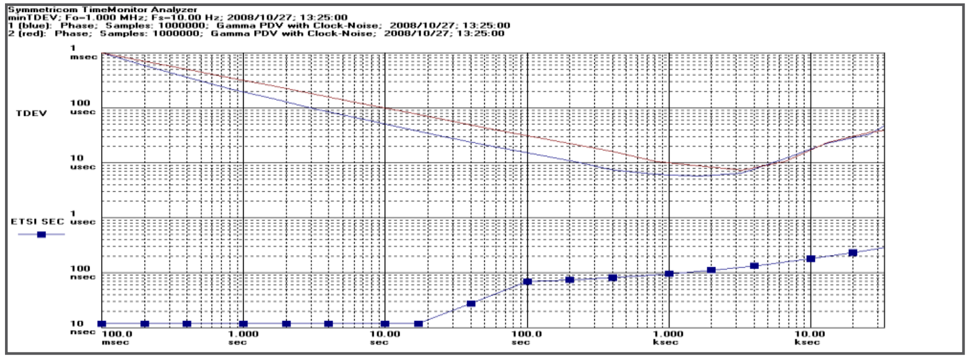




TDEV and minTDEV

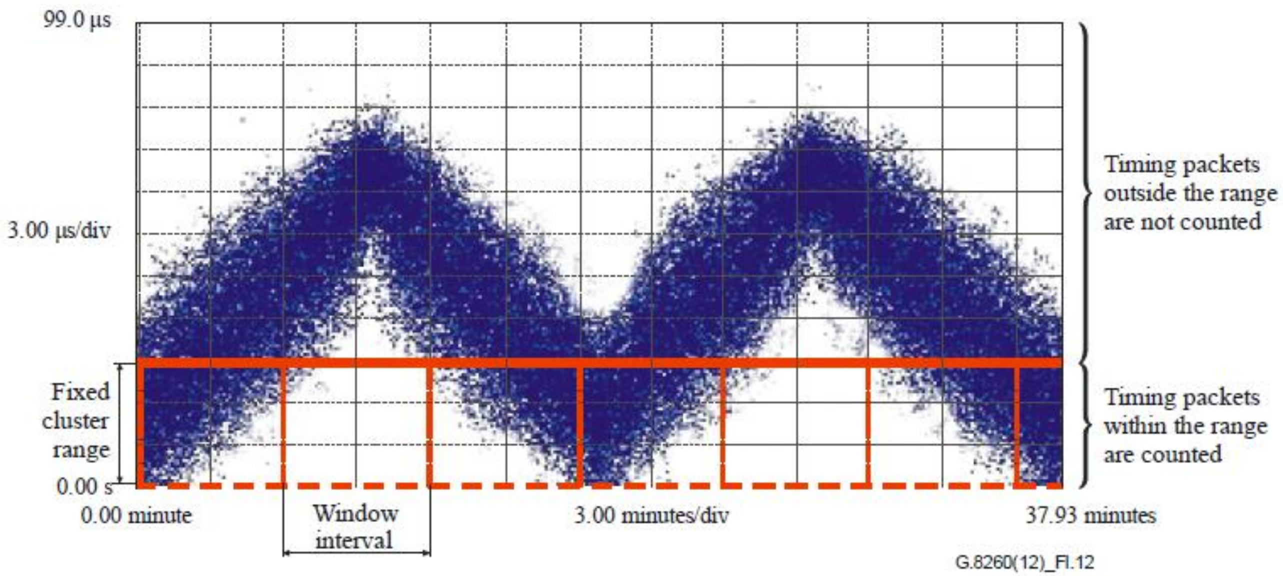


Peak-to-peak jitter = 11.5ms

Peak-to-peak jitter = 10ms

FLOOR PACKET PERCENTAGE

Family of metrics based on counting amount of packets, observed for any window interval of *t* seconds within a fixed cluster range starting at the observed floor delay and having a size δ

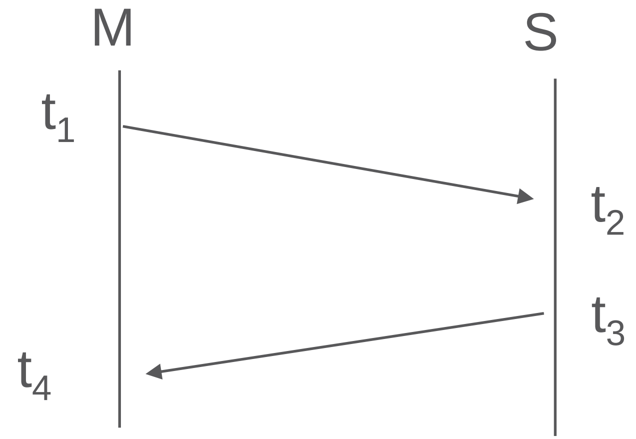


Floor Packet Percent (*FPP*) defined in terms of percentage of packets meeting these criteria

TIME SYNCHRONIZATION VIA PTP: ASYMMETRY RELATED IMPAIRMENTS

- The basic principle is to distribute Time sync reference by means of two-way time stamps exchange

Time Offset= $t_2 - t_1$ – Mean path delay
Mean path delay = $((t_2 - t_1) + (t_4 - t_3)) /2$



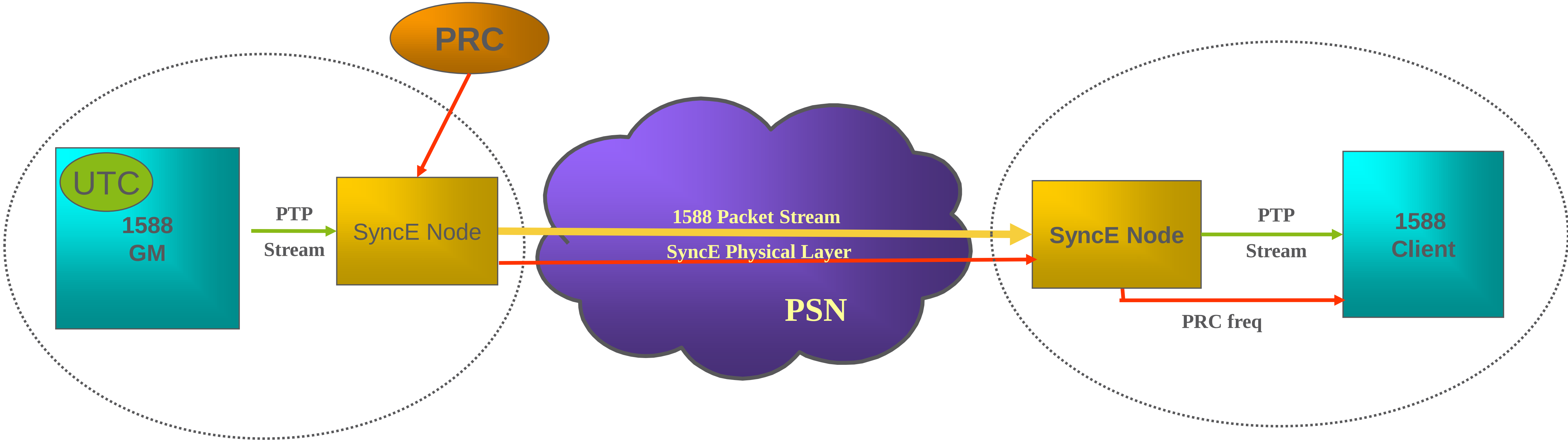
- As for NTP, also in case of PTP Symmetric paths are required:
  - Basic assumption: $t_2 - t_1 = t_4 - t_3$
  - Any asymmetry will contribute with half of that to the error in the time offset calculation (e.g. 3 μs asymmetry would exceed the target requirement of 1.5 μs)

ASYMMETRY DUE TO THE TRANSPORT TECHNOLOGIES

- Different paths in Packet networks
  - Traffic Engineering rules in order to define always the same path for the forward and reverse directions
- Different Fiber Lengths in the forward and reverse direction
  - Additional problem: DCF (Dispersion Compensated Fiber)
- Different Wavelengths used on the forward and reverse direction
- Asymmetries added by specific access and transport technologies
  - GPON
  - VDSL2
  - Microwave
  - OTN

COMBINED PTP-SYNCE

- SyncE as “frequency assistance” to 1588



- Gives immediate “frequency lock” to 1588 client
- SyncE & 1588 functionality may be in the same node/element
- SyncE might be used for “Time sync holdover”

REFERENCES

- Packet Timing in ITU-T: ITU-T G.826x series, G.827x series,
- ITU-T general definitions: G.810, G.8260
- NTP: IETF RFC 5905/6/7/8
- PTP: IEEE 1588-2008
- CES: RFC 5087, RFC 5086, RFC4533, ITU-T Y.1413, ITU-T Y.1453, MEF3, MEF 8

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